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AD-P003 905	VHF and UHF Propagation in the Canadian High Arctic.
AD-P003 906	Considerations Pertinent to Propagation Prediction Methods Applied to Airborne Microwave Equipments.

TROPOSPHERIC PROPAGATION ASSESSMENT

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ABSTRACT

It is well known that microwave propagation in a marine environment frequently exhibits unexpected behavior. The deviation from 4/3 earth propagation calculations is due to the fact that the vertical refractivity distribution of the troposphere rarely follows the standard lapse rate of -39 N/km. Instead, the troposphere is generally composed of horizontally stratified layers of differing refractivity gradients. The most striking propagation anomalies result when a layer gradient is less than -157 N/km, forming a trapping layer. In the marine environment, there are two mechanisms which produce such layers. An elevated trapping layer is created by the advection of a warm, dry air mass over a cold, moist air mass producing either a surface-based or an elevated duct which may affect frequencies as low as 100 MHz. A very persistent surface trapping layer is due to water evaporation at the air-sea interface. This surface, or evaporation, duct is generally thin, on the order of 10 m in vertical extent, and is an effective trapping mechanism for frequencies greater than 3 GHz. With the introduction of the Integrated Refractive Effects Prediction System (IREPS) into the US Navy, fleet units now have the capability to evaluate accurately the performance of their EM systems when the refractive environment is known. However, these units may have to plan for operations thousands of miles away under different refractivity conditions. To assist in planning, a worldwide upper air and surface climatology has been developed for use through the IREPS programs. The IREPS concept is reviewed and a description of the tropospheric ducting data base is presented.

INTRODUCTION

Any system which relies on propagation of electromagnetic waves in the earth's environment is to some extent propagation limited. There are a number of examples. Solar disturbances affecting the ionosphere can result in complete disruption of the Navy's vital hf communications and surveillance network. Refractive layers in the lower atmosphere can cause "holes" in shipboard radar coverage. Oceanic ducting phenomena may be exploited for over-the-horizon detection capabilities. Aerosols (clouds) are often the limiting factors in electro-optical systems. Nuclear explosions in the atmosphere can cause blackout of hf communications, seriously degrade both vlf and satellite strategic communications systems, and, for critical minutes, make radar useless by absorption, noise, and clutter. In general, these propagation phenomena are understood qualitatively and most can be modeled quantitatively with varying degrees of accuracy. However, the quantitative modeling often involves complex physical processes and cumbersome mathematical solutions. It has been, therefore, difficult to provide real time performance assessment to the user of equipment that depends on the propagation environment. The advent of small, inexpensive digital processing equipment changed this. Mini- and microcomputers with appropriate peripherals can store the geophysical models for calculating propagation conditions, perform the mathematical processing and provide a systems performance assessment in a form that is understandable and practical to the user.

Consequently, several propagation assessment systems were developed in the past decade. One example is the PROPHET (for propagation forecasting terminal) system for hf communications assessment (Richter et al., 1977). It uses satellite sensed solar x-ray emissions and other solar and geophysical data to provide, in real time, propagation conditions. This system was so successful that its capabilities were expanded to include propagation effects on geolocation systems, signal exploitation, vulnerability assessments, and development of propagation dependent tactics.

Another highly successful propagation assessment system, IREPS (Integrated Refractive Effects Prediction System) (Hitney and Richter, 1976), addresses microwave propagation in the lower atmosphere. Its capabilities are described in the following.

IREPS

In many maritime regions of the world, there exist frequent abnormal vertical distributions of refractive index that create non-standard propagation effects such as trapping or ducting and radio or radar holes. These effects can lead to both greatly extended operating ranges for certain cases and to greatly reduced ranges for other cases. Since the U.S. Navy operates in areas where such anomalous propagation is frequent, there is a requirement for a capability to assess and exploit atmospheric refractive effects and the resultant enhancement or degradation to naval surveillance, communications, and electronic warfare (EW) equipment. The system that has emerged to fulfill this requirement is IREPS. The IREPS concept is based on a shipboard computing capability which generates displays of electromagnetic equipment performance from inputs of both environmental and equipment parameters. The environmental inputs required are pressure, temperature, and humidity from a radiosonde ascent, or refractivity and altitude obtained directly from an airborne microwave refractometer, and surface measurements of air temperature, humidity, and wind velocity plus sea-surface temperature. Alternately, there is a capability to access a climatology of refractive effects for much of the world's ocean areas which will display and provide typical environmental inputs for IREPS processing. This climatology will be discussed in detail later in this paper.

There are several products from IREPS, but most widely used is the coverage diagram, an example of which is shown in figure 1. The coverage diagram shows the vertical region in space on a spherical altitude-versus-range plot where a specified radar, communications, or EW system will achieve or exceed one or more predefined levels of performance. The example is for the case of an arbitrary 400 MHz air search radar where the three shaded regions represent the .9, .5, and .1 probability of detection of a 1 square meter target. The environmental conditions for the example were characterized by a strong surface-based duct that has resulted in extended ranges below about 500 m. The equipment parameters required for the coverage diagram are frequency, polarization, emitter antenna height, antenna pattern type, vertical beamwidth, antenna pointing angle, and one or more free-space ranges associated with desired levels of performance. Scale factors for the display must also be specified.

A second IREPS product that is quite valuable is the path loss display that shows one-way path loss in dB versus range. Figure 2 is an example of this product for an environmental case characterized by a standard atmosphere and for surface-to-air 300 MHz UHF communications equipment. The equipment parameters required for the path loss display are the same as those for the coverage diagram, plus a specification of receiver or target height. The horizontal dashed line threshold is based on the free-space range specified and establishes the maximum path loss that can be tolerated for the equipment to operate at or above the desired level of performance. In this example, the threshold is based on acceptable communications ability at 200 km in free space. As the example shows, this same level of performance for a receiver at 1000 m altitude will be achieved out to ranges of 120 km for the environmental conditions specified. The loss display can be used effectively to assess radar detection ranges and Electronic Support Measurement (ESM) intercept ranges as well as communication ranges.

Other major IREPS products that exist but for which no examples are presented here are tables of maximum ESM intercept ranges for predefined lists of emitters, and tables of expected maximum surface-search radar ranges for predefined lists of surface targets.

The models upon which all of the products are based are combinations of ray-optics, simplified full-wave solutions, semi-empirical formulations based on measured data, and interpolations to smooth transitions between the various models. In the optical region, standard ray-trace techniques are used along with calculations of the interference between direct and sea-reflected rays. Reflection coefficients for horizontal, vertical, or circular polarization, modified for ocean roughness, and the spherical-earth divergence factor are calculated as necessary. For ranges well beyond the horizon, there are models to account for standard diffraction, effects of the evaporation duct and surface-based ducts from elevated layers, and tropospheric scatter. The models for diffraction and the evaporation duct are based on simple-to-calculate functions that have been fit to the results of numerical full-wave solutions. The model for the surface-based duct is largely empirical in nature.

IREPS displays that are under development combine results from the various products aleady discussed to show composite effects of propagation on a formation of ships. Figure 3 shows an example for an aircraft carrier and three escort ships. The darker shaded regions on this display represent the composite areas of detection of a particular surface target by the ships' radars. The lighter shaded region represents the composite vulnerability of the ships' emissions to reception by an adversary's ESM capability. Such a display will allow a user to quickly evaluate the capabilities and trade-offs between detection and counter-detection in light of the current propagation environment.

All of the IREPS products require a description of the atmospheric refractivity conditions in which the EM system is expected to operate. Obviously, for the shipboard users, the most recent upper air sounding provides the best description of the environment. However, the need may arise for environmental data at an area far removed from the ships' present location. In response to this need, a climatology of worldwide maritime refractivity conditions has been compiled and made directly available to the IREPS users.

TROPOSPHERIC DUCT CLIMATOLOGY

The purpose of the climatology is to provide an estimation of the tropospheric ducting conditions for any maritime region. As with all statistical descriptions of the environment it is intended to aid in long range or long term planning. Since fleet units are highly mobile a description of the expected ducting environment at distant locations may aid in the formulation of tactics. Consider, for example, an air strike against a radar protected installation. The classical strike aircraft altitude is low to the surface to achieve maximum penetration before detection. That is, the strike aircraft attempt to fly in under the radar horizon. However, in some regions of the world, strong surface-based ducts are observed to occur 50% of the time or more. As a surface-based duct may greatly increase the radar detection range against low flying targets, the classical strike aircraft altitude would be the worst possible location for surprise. Without insitu measurements, which are always preferable to statistical descriptions, the climatology can supply needed data for making judicious decisions. In addition, the climatology provides the meteorological officer with a guide to determine the frequency or need for ship launched upper air soundings. In general, few soundings are required at northern latitudes to assess the local refractivity conditions whereas, in regions of persistent ducting, two or more soundings per day may be needed.

The climatology consists of data from two distinct sources. The first source is upper air radiosonde observations describing the vertical refractivity profile. These profiles are derived from an analysis by Ortenburger (1977) of all radiosonde stations reporting for five selected years. Pertinent profile statistics were extracted from this analysis for 399 coastal, island and weather ship stations. On figure 4, the dots mark the location of the radiosonde stations included in the climatology. Shipboard surface meteorological observations comprise the second source of data. The National Climatic Center, Asheville, NC, processed all shipboard surface observations taken during the years 1970 through 1979 to obtain histograms of evaporation duct height, wind speed and other parameters. Calculations of the evaporation duct height are based on the theory proposed by Jeske (1971) and are described in Hitney (1975). These histograms were developed for ocean regions in grids of 10° latitude and 10° longitude known as Marsden Squares. A total of 213 such squares are included in the climatology and are shown as the shaded ocean areas in figure 4.

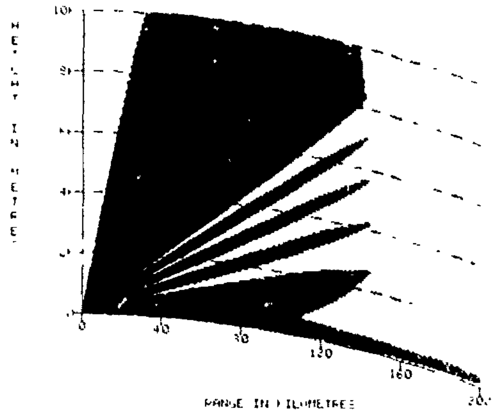

Figure 1. 400 MHz air search radar coverage diagram. The shaded regions represent the .9, .5, and .1 detection probabilities for a target of 1 square metre cross section.

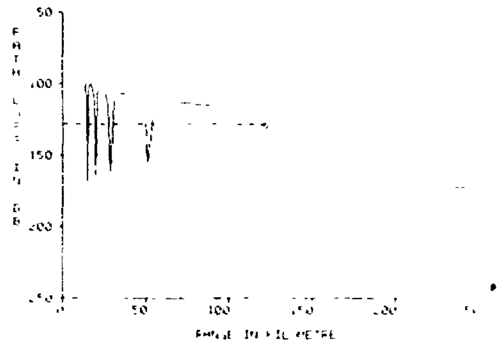

Figure 2. Path loss display for a 300 MHz surface-to-air communication system. Successful communication is shown for ranges where the predicted path loss (solid line) is less than the maximum path loss threshold (dashed line).

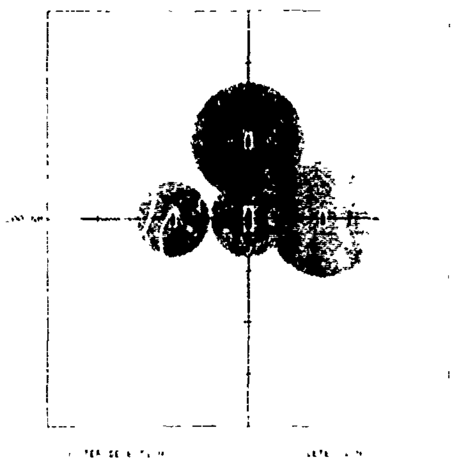

Figure 3. Display of detection and counter detection envelopes for a formation of ships. The darker shaded circular region centered on a ship shows that ships' detection capability against a particular surface target. The lighter shaded region represents the area where a specified ESM system is able to counter detect the ships' emissions.

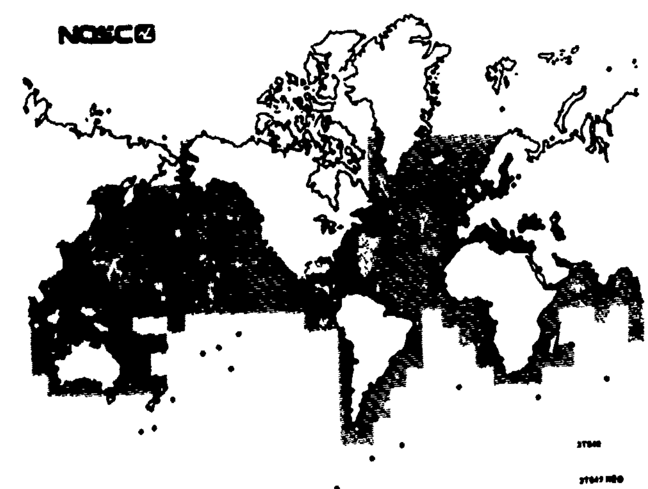

Figure 4. Geographic extent of the tropospheric ducting climatology. Shaded ocean regions indicate areas containing surface meteorological observations. Dots show the location of the radiosonde stations.

PERCENT OCCURRENCE OF ENHANCED SURFACE-TO-SURFACE RADAR ESM COM RANGES:

FREQUENCY	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
100 MHz	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1 GHz	6	3	4	1	1	1	8	4	6	12	6	9	2	1	1
3 GHz	7	3	5	2	1	1	9	5	7	14	7	10	2	1	1
6 GHz	13	8	11	3	1	2	14	8	11	27	17	22	9	5	7
10 GHz	37	30	34	19	15	17	31	22	26	57	48	52	43	35	39
20 GHz	60	53	57	46	40	43	50	42	46	75	69	72	69	62	65

SURFACE BASED DUCT SUMMARY:

PARAMETER	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
Percent occurrence	1	2	1	0	0	0	1	2	2	2	4	3	0	0	0
AVG thickness Kft			.31			.30			.25			.36			.31
AVG trap freq GHz			1.4			.45			1.7			1.0			2.5
AVG lyr grd -N/Kft			136			167			135			136			105

ELEVATED DUCT SUMMARY:

PARAMETER	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
Percent occurrence	10	12	11	4	5	5	10	10	10	22	23	23	5	8	7
AVG top ht Kft			3.4			3.5			2.8			3.9			3.5
AVG thickness Kft			.29			.20			.28			.39			.29
AVG trap freq GHz			1.1			1.8			1.2			.56			.94
AVG lyr grd -N/Kft			54			54			52			54			56
AVG lyr base Kft			3.2			3.3			2.6			3.5			3.2

EVAPORATION DUCT HISTOGRAM IN PERCENT OCCURRENCE:

PERCENT OCCURRENCE	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
0 to 10 Feet	18	20	19	22	25	24	25	29	27	12	13	12	12	15	13
10 to 20 Feet	22	26	24	31	34	33	25	30	27	14	18	16	19	23	21
20 to 30 Feet	23	24	23	27	25	26	19	20	20	19	22	21	26	27	25
30 to 40 Feet	16	16	16	12	12	12	12	10	11	18	20	19	23	21	22
40 to 50 Feet	8	6	7	3	2	2	5	3	4	13	12	12	12	9	10
50 to 60 Feet	4	3	4	1	1	1	3	2	2	8	6	7	5	3	4
60 to 70 Feet	2	1	1	0	0	0	1	1	1	3	2	3	1	1	1
70 to 80 Feet	1	0	1	0	0	0	1	1	1	2	1	1	0	0	0
80 to 90 Feet	1	0	0	0	0	0	1	0	1	1	1	1	0	0	0
90 to 100 Feet	0	0	0	0	0	0	1	0	1	1	0	1	0	0	0
above 100 Feet	5	2	4	1	1	1	8	3	5	11	4	7	2	1	1
Mean height Feet	33	25	29	22	19	21	33	24	28	45	33	39	30	26	28

GENERAL METEOROLOGY SUMMARY:

PARAMETER	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
% occur EL&SB dcts			0			0			0			1			0
% occur 2+ EL dcts			1			0			0			3			1
AVG station N			323			316			322			333			319
AVG station -N/Kft			13			12			12			14			12
AVG sfc wind Kts	16	16	16	18	18	18	14	13	14	14	14	14	20	20	20

Figure 5. IREPS Historical Propagation Conditions Summary for the North Sea region at 55° N latitude and 5° E longitude.

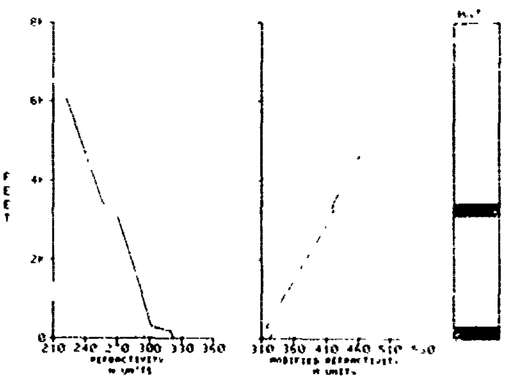

Figure 6 Profiles of the refractivity and modified refractivity versus height constructed from the yearly day and night statistics of Figure 5.

A sample of the IREPS Historical Propagation Conditions Summary is shown by figure 5. This product describes the ducting climatology for a specified location in the North Sea at 55° N latitude and 5° E longitude. The closest radiosonde station, in the great circle sense, contained in the climatology is Schleswig, Germany, located at 54°31' N, 9°33' E. The closest surface observation source is Marsden Square 216 which is centered at 55° N, 5° E. From these two data sources, the program constructs five tables for three month time periods and an overall yearly average. The five time period columns are further separated into day, night, and day and night combined columns for diurnal analysis.

The first table provides the percent of time that surface-to-surface communication ranges exceed the ranges expected under standard atmospheric conditions. For example, on a yearly basis a surface-to-surface communication system operating in this area using frequencies near 6 GHz is expected to experience enhanced ranges 13% of the time during the day and 8% of the time during night. A similar system using frequencies near 10 GHz is predicted to observe greater ranges 34% of the time.

The next two tables describe the percent occurrence and geometries of surface-based and elevated ducts. These data are derived directly or computed from Ortenburger's results. In his analysis, diurnal statistics of the duct geometries were not generated and this information is not available within the climatology.

The final two tables show the percent occurrence of evaporation duct heights in ten foot intervals, mean evaporation duct height, joint probability of an elevated duct with a surface-based duct, probability of two or more elevated ducts, station refractivity and surface wind speed.

Figure 6 illustrates the vertical refractivity and modified refractivity profiles constructed for the specified location. These profiles are generated from the yearly day and night statistics and include both the surface-based and elevated ducts. Optional profiles can be created for standard atmospheric conditions (no ducts), surface-based duct only, or elevated duct only for any of the time periods shown in figure 4. The mean evaporation duct height and the average surface wind speed for the time period selected accompany the profile data. These data become available for use by the IREPS propagation prediction programs.

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DISCUSSION

S. Rotheram (U.K.): 1) Evaporation duct predictions such as those produced by IREPS and by our own methods indicate prediction errors for path loss of ± 20 dB. Could you comment on the operational significance of these errors?

2) Roger Helvey of PMTC has pointed out that temperature induced humidity errors systematically bias the lowest part of radiosonde ascents, producing spurious surface based ducts. This appears to invalidate much of the Sylvania data base mentioned in the paper.

K.D. Anderson (U.S.): 1) Statistically, the predictions are very good. We question the validity for operational purposes, but it is currently the best that can be done.

2) This is true for the surface layer, although the elevated trapping layers are probably very good observations. Roger is working on a possible solution for the surface layer problem.

T. Almond (U.K.): I think that it is important to ensure confidence in the IREPS model. It cannot be 100% efficient.

K.D. Anderson (U.S.): I agree with you. It is a difficult job, but one of the reasons for the success of IREPS has been the open and sometimes blunt communication between the laboratory and fleet users.

F. Thomsen (Denmark): Your coverage diagrams show a distinguished lobing effect caused by reflection of the transmitted energy by the sea surface. The exact position and depth of these nulls are very dependent on the sea surface stat , i.e., surface roughness and slope distribution. Has this effect been considered?

K.D. Anderson (U.S.): Yes. We do include surface roughness effects in the models for the reflection coefficient. However, we do not account for clutter effects. The clutter is very difficult to model with any success.

T.J. Boulton (U.K.): 1) Data is available from the South Atlantic via the British Navy.

2) With regard to Vertical Coverage Diagrams, is the HP 9845 locally programmable to account for antenna characteristics?

K.D. Anderson (U.S.): All of the electromagnetic system parameters can locally be changed. These parameters include antenna heights, types ([sin x]/x, Omni, height finder, fan beam, etc.), power, sensitivity, and many more. We have tried to make the IREPS program as "user friendly" as possible.

E. Vilar (U.K.): I would like to comment on the subject of reliability of radiosonde measurements. We have found, in an experiment using a tethered balloon and scanning the height h between 800 and 1000 meters up and down at various speeds, that the wet bulb temperature T' features were smoothed out during the usual ascent and descent speeds of several meters per second. In order to see layers of 10 meters or less in thickness and to receive a good indication of the refractivity N(h) gradient within the layer, one needed ascent and descent speeds of about one meter per second. This was clearly unsatisfactory and inconvenient. The manufacturer later acknowledged that the time constant, defined in the usual manner, response/time, could be as high as 10 to 15 seconds. Could you comment on the possible impact of this on your data bank?

K.D. Anderson (U.S.): The large structures are most important. It is believed that these are adequately sens. by the beam.